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The Chainpur Meteorite

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INTRODUCTION

This remarkable meteorite fell on May 9, 1907, at 1.30 P.M. as a shower of stones at and near the village of Chainpur (latitude 21° 51′ N., longitude 83° 29′ E.) on the Ganges Plain. Some 8 kilograms were recovered. The circumstances of the fall and the recovery of the stones, and a brief description of the material, were given by Cotter (1912).

One of us (Mason), when examining the Nininger Meteorite Collection in Arizona State University in January, 1962, noticed the unusual appearance of a fragment of this meteorite, particularly the large chondrules and the friable texture, and obtained a sample for further investigation. Shortly thereafter, Keil was studying the Nininger Meteorite Collection, also remarked on this meteorite, and began independently to investigate it. In the meantime, Mason had sent a sample to Wiik for analysis. Under these circumstances, it seems desirable to report all these investigations in a single paper.

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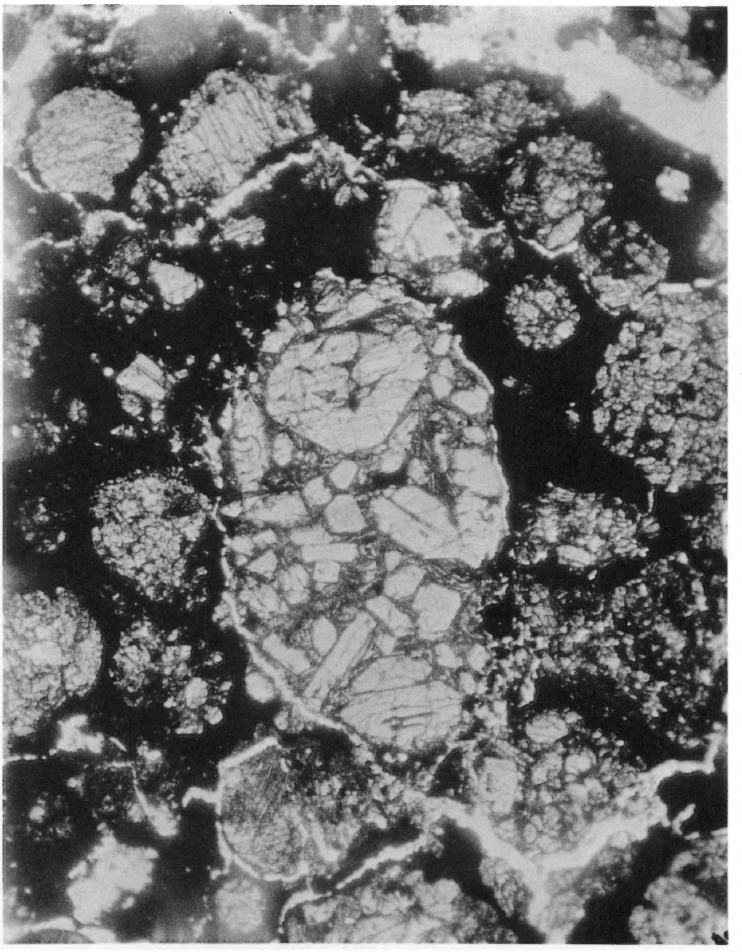

FIG. 1. Photomicrograph of a thin section of the Chainpur meteorite, showing chondrules of olivine and pyroxene in a black matrix. The black matrix contains nickel-iron and troilite, but the color is largely due to finely divided carbonaceous matter. The large chondrule in the center is made up of numerous individual olivine crystals; the other chondrules contain both olivine and pyroxene, or pyroxene alone. × 30.

MINERALOGICAL COMPOSITION AND STRUCTURE

A broken surface of the Chainpur meteorite is dark gray in color, with shot-like chondrules standing out prominently; some of them are as much as 4 mm. in diameter, but the majority are smaller (1–2 mm.). The

chondrules are dark gray to black on the outside, but sawn surfaces show that they are gray to white in the interior. Comparatively little nickel-iron can be seen with a hand lens, and it is present as small isolated grains, sometimes, however, concentrated around the periphery of individual chondrules. The mass of the meteorite is only weakly magnetic.

A thin section (fig. 1) shows numerous chondrules, varying in size and internal structure, in a black opaque groundmass. Some of the chondrules are made up of numerous individual idiomorphic olivine crystals in a turbid mesostasis. Others consist of an aggregate of pyroxene crystals with low birefringence, polysynthetic twinning, and oblique extinction, evidently low-calcium clinopyroxene. Some pyroxene chondrules have the typical eccentrically radiating aggregates of thin plates (Fredriksson, 1963). Some chondrules are extremely fine-grained. Some consist of olivine and pyroxene within a single chondrule.

The density of a piece of this meteorite was determined by measuring the apparent loss of weight on suspension in carbon tetrachloride, and was found to be 3.40. Since the meteorite is quite porous, the piece was placed in a beaker under a bell jar, which was evacuated with an oil pump before running in the carbon tetrachloride.

The principal minerals in the meteorite are olivine and pyroxene (largely or entirely low-calcium clinopyroxene). Minor constituents are nickel-iron and troilite. Other minerals probably present in small amount, but not certainly identified, include plagioclase, chromite, and apatite or merrillite (or both). Notes on the individual minerals follow:

Olivine: An X-ray diffractometer trace immediately reveals the peculiar nature of the olivine in this meteorite. Instead of sharp and well-defined peaks, as is usual for the great majority of chondrites, the olivine reflections appear as broad humps, which indicates inhomogeneous olivine with a considerable range of composition, which in turn is confirmed by the great variability in refractive indices from grain to grain in an immersion mount. The position and shape of the diffractometer reflections were interpreted as indicating olivine with composition ranging from Fa_0 to Fa_{40} (0 to 40 mol per cent Fe_2SiO_4), with a mean composition around Fa_{25}. This has been confirmed by measurements on individual grains by the electron-beam microprobe.

Clinopyroxene: In chondrites with a chemical composition similar to that of Chainpur (such as Knyahinya, for example), the pyroxene phase is hypersthene (orthorhombic), sometimes with accessory clinopyroxene. In Chainpur, however, the pyroxene phase is monoclinic, and orthorhombic pyroxene, if present, is there in small amount. The optical properties and diffraction pattern of the clinopyroxene in Chainpur can

TABLE 1
CHEMICAL COMPOSITION OF THE CHAINPUR METEORITE

A		B		C	
Fe	3.02	Fe	19.78	Si	37.64
Ni	0.96	Si	18.98	Mg	34.69
Co	0.04	Mg	15.16	Fe	19.71
FeS	6.44	S	2.35	Al	2.87
SiO_2	40.63	Al	1.39	Ca	1.54
TiO_2	0.09	Ca	1.11	Na	1.36
Al_2O_3	2.63	Ni	0.96	Ni	0.91
FeO	16.29	Na	0.56	Cr	0.51
MnO	0.32	Cr	0.48	P	0.29
MgO	25.14	C	0.36	Mn	0.25
CaO	1.55	Mn	0.25	K	0.14
Na_2O	0.75	P	0.16	Ti	0.05
K_2O	0.12	H	0.12	Co	0.04
P_2O_5	0.36	K	0.10		100.00
H_2O+	1.00	Ti	0.05		
H_2O-	0.10	Co	0.04		
Cr_2O_3	0.70	(O	38.15)		
C	0.36		100.00		
	100.50				

A Chemical analysis in weight per cent of the oxides of the electropositive elements.
B Chemical analysis in weight per cent of the elements, with oxygen to bring the sum to 100.
C Atomic per cent of the elements on a volatile (H, O, C, S)-free basis.

be identified either with those of clinohypersthene or pigeonite, the difference between these two minerals being that pigeonite has a somewhat higher calcium content (the boundary between them is arbitrary and not clearly defined). The low calcium content of the pyroxene shown by

TABLE 2
NORMATIVE COMPOSITION OF THE CHAINPUR METEORITE

Olivine	45.1
Hypersthene	29.0
Diopside	1.6
Albite	6.4
Anorthite	3.4
Orthoclase	0.7
Chromite	1.0
Apatite	0.8
Ilmenite	0.2
Troilite	6.4
Nickel-iron	4.0

electron-beam microprobe analyses shows that the mineral is best described as clinoenstatite to clinohypersthene, depending on the iron content. Its composition also varies from grain to grain, and within individual grains, but not to the same extent as does that of olivine.

CHEMICAL COMPOSITION

The chemical analysis is given in table 1, in the conventional form expressed as oxides, troilite, and metal; in terms of the individual elements as determined by analysis, with oxygen to bring the total to 100; and recalculated as atom percentages with the elimination of H, O, C, and S.

The analysis shows that the chemical composition of Chainpur is similar to that of many other chondrites. The figure for total iron (19.78%) indicates that the meteorite belongs to the low-iron (L) group as defined by Urey and Craig (1953), a group that includes many hundreds of olivine-hypersthene chondrites (Mason, 1963). The analysis of Chainpur is almost identical with that of Knyahinya recently published by Mason and Wiik (1963). Possibly significant features are the amounts of C (0.36%) and H_2O+ (1.00%), which suggest that the black groundmass is pervaded with organic material similar to that in the carbonaceous chondrites.

The normative mineral composition, expressed as weight percentages, is given in table 2. The observed mineral composition agrees well with that calculated as the norm. The proportion of olivine to pyroxene agrees with estimates from the thin section and X-ray diffraction patterns. Feldspar was not recognized microscopically or in X-ray diffraction patterns. The amount present must be considerably less than the 10.5 per cent in the norm, probably because much of the Al_2O_3 and CaO calculated as feldspar is actually combined in the pyroxene.

ELECTRON MICROPROBE X-RAY ANALYSES

Samples for the electron microprobe analyses were prepared as follows: Several fragments of the meteorite were disaggregated in an agate mortar by gentle rubbing. Four size fractions, consisting of chondrules, fragments of chondrules, and matrix material, were obtained by sifting with sieves of different mesh sizes. From these fractions, undamaged individual chondrules were separated under a microscope and carefully cleaned from matrix material around them. The chondrules in the different fractions fell in the following size ranges: fraction 1, 2.0 to 2.5 mm.; fraction 2,

1.0 to 1.4 mm.; fraction 3, 0.4 to 0.6 mm.; and fraction 4, 0.3 to 0.4 mm. Approximately 10 to 15 chondrules from each size fraction were used in the preparation of polished sections. The sections were coated with a layer of carbon 200 to 300 Å thick. The chondrules of each size fraction were studied by measuring the iron, magnesium, and calcium content of 10 to 20 individual olivine and pyroxene grains in each chondrule. The measurements were conducted with a modified ARL electron microprobe analyzer (Applied Research Laboratories, Glendale, California). Usually,

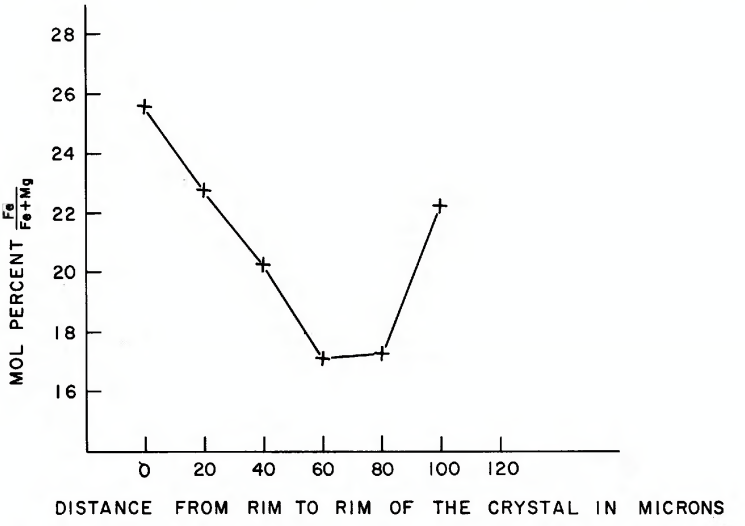

FIG. 2. Zonar structure in olivine; olivine crystal no. 8, chondrule 4, in fraction 1 (diameter of chondrules 2.0, to 2.5 mm.).

five measurements, 5 to 8 microns apart, were made on each grain. In the case of larger grains, their zonar structure was ascertained by moving the sample in steps of 20 to 40 microns under the fixed beam, thus covering the grain with rows of analyses.

For the quantitative analysis of iron, magnesium, and calcium in the olivines and pyroxenes, chemically analyzed olivines, clinopyroxenes, and an andesine were used as standards. The chemical analyses and the degree of homogeneity of these standards were controlled with the microprobe by analyzing them against pure metallic iron and magnesium standards. After corrections were made for background, deadtime, mass-absorption, fluorescence (according to the suggestions made by Wittry, 1962), and atomic number, agreement with the chemical analyses was found to be excellent, namely, within $\pm$ 0.3 per cent for Fe. Calibra-

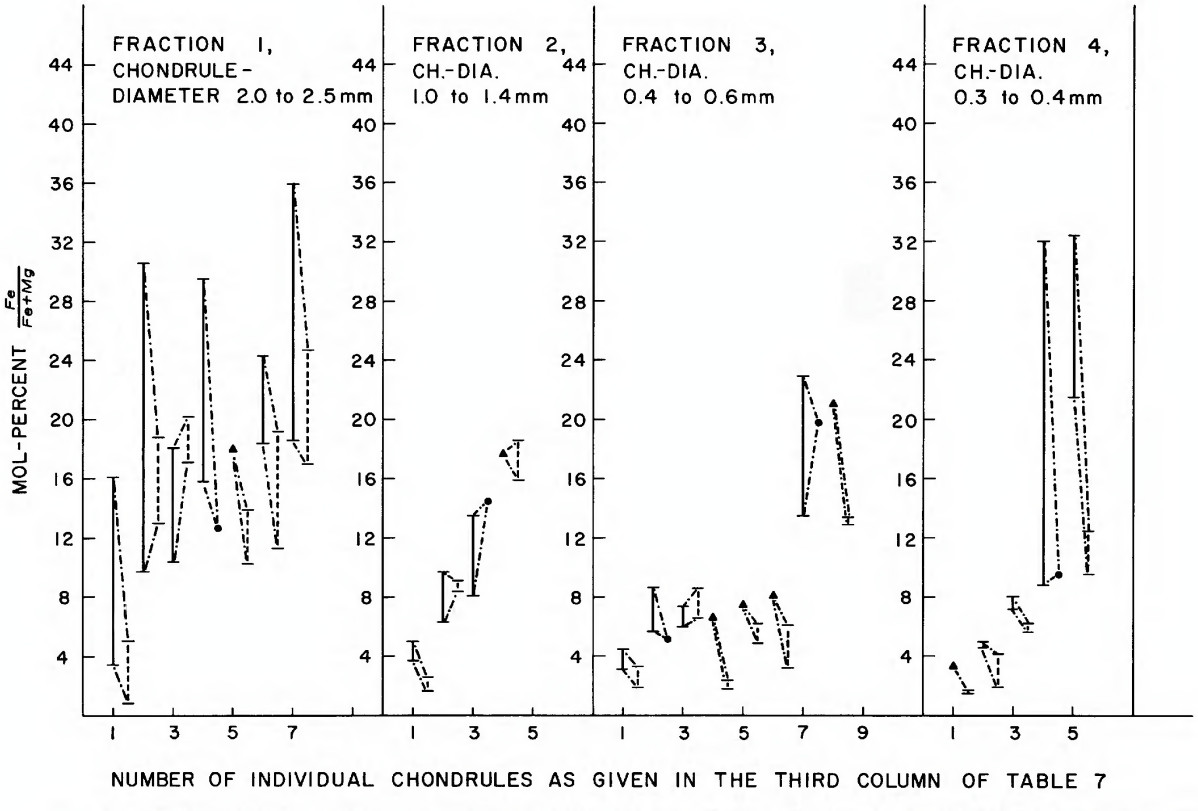
FRACTION 1, CHONDRULE-DIAMETER 2.0 to 2.5mm
FRACTION 2, CH.-DIA. 1.0 to 1.4mm
FRACTION 3, CH.-DIA. 0.4 to 0.6mm
FRACTION 4, CH.-DIA. 0.3 to 0.4mm
MOL-PERCENT Fe/Fe+Mg
NUMBER OF INDIVIDUAL CHONDRULES AS GIVEN IN THE THIRD COLUMN OF TABLE 7

FIG. 3. Maximum and minimum values of the mol per cent Fe/Fe+Mg in coexisting olivines and pyroxenes in individual chondrules; ——— ▲, olivines; – – – – – ●, pyroxenes; — . — . — . (dash-dot lines) connect the maxima and minima values of coexisting olivines and pyroxenes in the given chondrules.

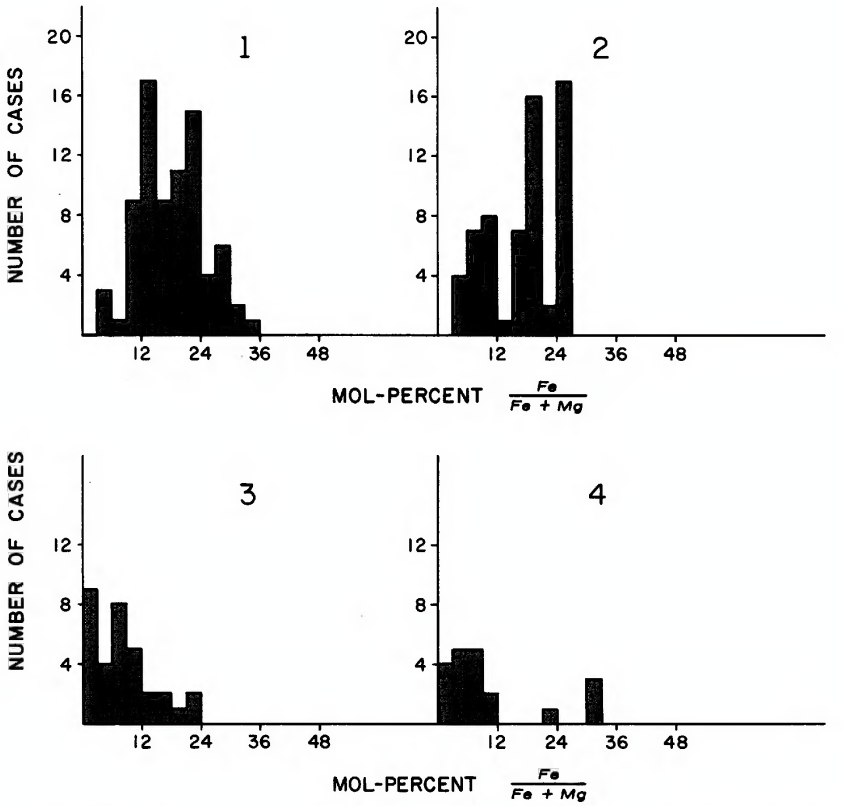

FIG. 4. Mol per cent Fe/Fe+Mg in olivine. Analyses of (1) 78 olivines, (2) 62 olivines, (3) 33 olivines, and (4) 20 olivines from individual chondrules of the fractions 1, 2, 3, and 4, respectively.

tion curves were drawn for both olivines and pyroxenes by use of these numbers, and further values were evaluated graphically (Fredriksson and Keil, 1963; Keil and Fredriksson, 1963a; in press, a). The relative standard error for both olivines and pyroxenes was found to be $\pm$ 0.1 per cent for Fe, $\pm$ 0.2 per cent for Mg, and $\pm$ 0.1 per cent for Ca.

The results of the measurements are listed in tables 3 through 6. Some important differences in comparison to ordinary chondrites are apparent. One of the most significant qualities of the majority of chondrites is the fact that the composition of olivine and pyroxene in different chondrules, as well as in the matrix of a given chondrite, is constant, varying less than $\pm$ 0.5 weight per cent for Fe and Mg (Fredriksson and Keil, 1963; Keil and Fredriksson, in press, a). Exceptions are some highly recrystallized

chondrites (Keil and Fredriksson, in press, a), carbonaceous chondrites (Ringwood, 1961; Keil and Fredriksson, in press, b), and the olivine-pigeonite chondrites (Mason, 1963). In Chainpur, however, strong variations in the composition of olivine and pyroxene occur from chondrule to chondrule, as well as within single chondrules, thus making this meteorite quite unusual among the known chondrites. In tables 3 through 6 the measurements of numerous single crystals in a large number of different chondrules from various size fractions are listed. The variability in compo-

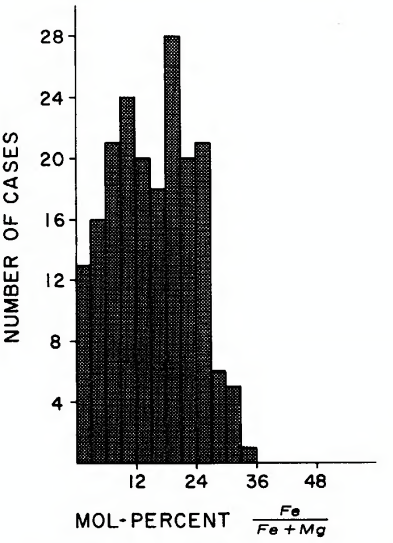

FIG. 5. Mol per cent Fe/Fe+Mg for the total 193 individual olivine crystals investigated (tables 3 through 6).

sition even inside single chondrules is largely due to extensive zonar structure, particularly of the olivine crystals (fig. 2). The grains in table 3 through 6 that do not show zoning (e.g., list only one value for Fe and one for Mg) may well have zonar structure, although their particular orientation in the section plane does not allow one to measure those variations. Furthermore, the listed variability in composition for many grains does not necessarily give true maxima and minima values for the given crystal, but again depends upon the chance orientation of the crystal to the plane of section.

Because of the zonar structure of the individual olivine and pyroxene crystals within single chondrules, it is difficult to demonstrate the differences in composition from chondrule to chondrule graphically. In order

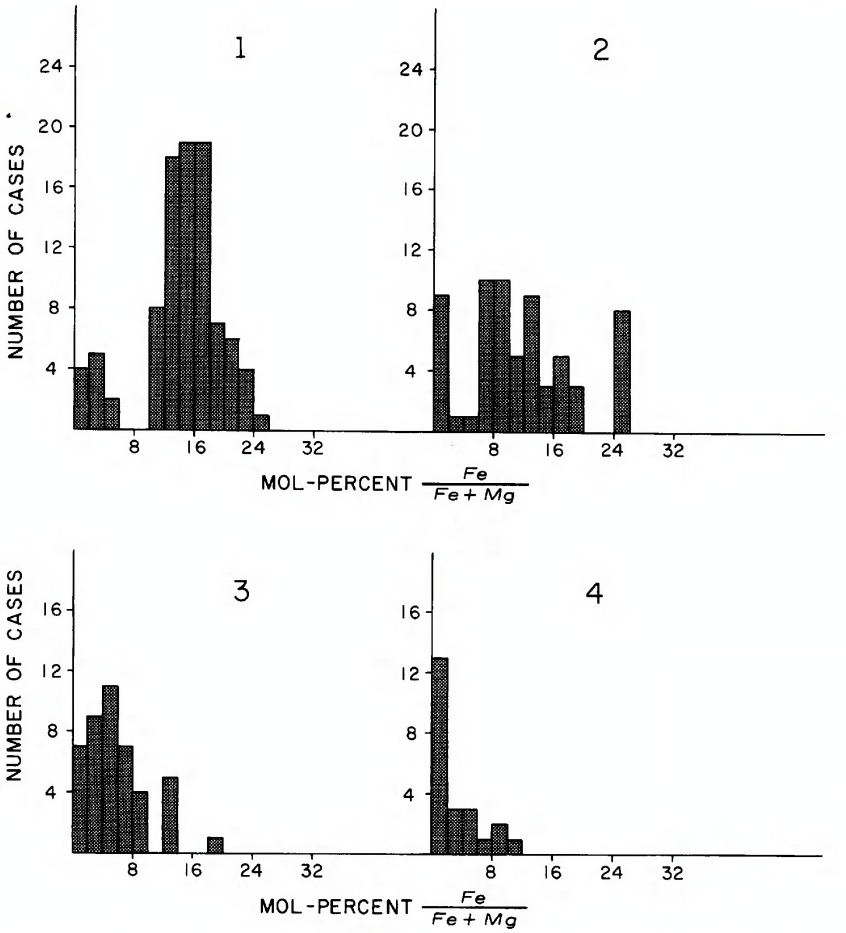

FIG. 6. Mol per cent Fe/Fe+Mg in pyroxenes. Analyses of (1) 93 pyroxenes, (2) 64 pyroxenes, (3) 44 pyroxenes, (4) 23 pyroxenes from individual chondrules of the fractions 1, 2, 3, and 4, respectively.

to make the numerous figures given in tables 3 through 6 somewhat more intelligible, the maxima and minima values for olivine and pyroxene for each chondrule investigated are compiled in table 7. In figure 3 the maxima and minima values for Fe/Fe+Mg in olivine and pyroxene are plotted for each chondrule and separated into the four fractions investigated. The numbers for the single fractions are listed in order of increasing Fe/Fe+Mg in olivine. Chondrules in which either no olivine or no pyroxene was found were eliminated from the graph. The numbers on the abscissa of the graph refer to the numbers given in the second column

in table 7. Figure 3 gives an impression of the variability in composition of olivine and pyroxene within single chondrules, as well as of the relation between the Fe /Fe+Mg ratios in olivine to pyroxene. Figure 3 indicates that (a) generally the variability in composition of the olivines is larger than that in pyroxene, and (b) that usually the iron content for the average of coexisting olivines and pyroxenes within a single chondrule is higher in the olivine than in the pyroxene, in agreement with the findings by Bowen and Schairer (1935) for coexisting olivine-pyroxene pairs in the system FeO-MgO-SiO_2. The exceptions from this rule in case of the Chainpur chondrite seem to have no genetical meaning, but might

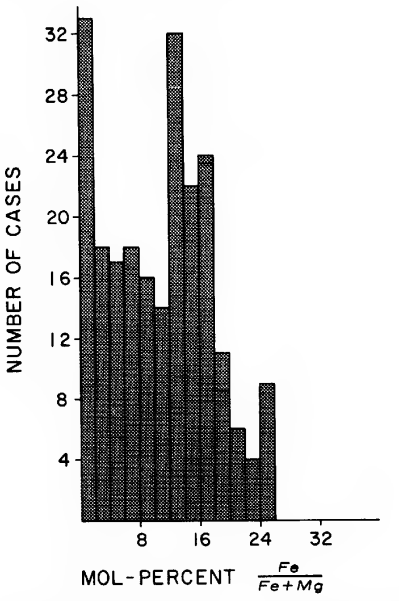

FIG. 7. Mol per cent Fe /Fe+Mg for the total 224 individual pyroxene crystals investigated (tables 3 through 6).

simply be due to the random selection of the grains analyzed and their zoning, which depends greatly upon the orientation of the crystals to the section plane. In figures 4 through 7 the Fe /Fe+Mg ratios for olivine and pyroxene are plotted in frequency distribution diagrams. For the individual crystals with zonar structure the average values were used in the graphs. Figure 4 shows the Fe /Fe+Mg ratios for the olivines measured, separated into the diagrams for every size fraction measured, while figure 5 gives a histogram for the total 193 olivines analyzed. Figures 6 and 7 are similar diagrams for the pyroxenes investigated.

TABLE 3

COMPOSITION OF COEXISTING OLIVINES AND PYROXENES IN SEPARATED INDIVIDUAL CHONDRULES (FRACTION 1, DIAMETER OF THE CHONDRULES, 2.0 TO 2.5 MM.)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
Chondrule 1					
Olivine	—	—	—	—	—
Pyroxene	1	7.5	18.6	0.16	14.9
	2	7.6	18.5	0.08	15.2
	3	7.6–8.8	18.6–17.7	0.15	15.1–17.8
	4	7.9	18.4	0.16	15.8
	5	7.9	18.7	0.07	15.5
	6	8.0–9.2	18.5–17.7	0.27–0.42	15.8–18.5
	7	8.2	17.7	0.14	16.8
	8	8.4	18.2	0.35	16.7
	9	8.5	18.1	0.13	17.0
	10	8.5–8.9	18.1–17.8	0.16	17.0–17.9
	11	8.6	18.1	0.19	17.1
	12	8.6	18.9	0.11	16.5
	13	8.8	18.0	0.17	17.6
	14	8.8	19.0	0.15	16.8
	15	8.9	18.6	0.15	17.2
	16	8.9	18.0	0.18	17.7
	17	8.9	18.0	0.16	17.7
	18	9.3	18.2	0.22	18.2
	19	9.3	18.4	0.18	18.0
	20	10.4	17.1	0.33	20.9
Chondrule 2					
Olivine	1	14.1–14.8	26.6–24.8	< 0.1	18.8–20.6
	2	14.9–16.3	25.9–25.4	< 0.1	20.0–21.8
	3	15.7	25.5	< 0.1	21.1
	4	16.3	24.9	< 0.1	22.2
	5	18.5	23.6	< 0.1	25.4
	6	18.8–21.3	23.5–21.9	< 0.1	25.8–29.8
	7	19.4–20.2	23.2–22.4	< 0.1	26.7–28.2
	8	21.7	21.8	< 0.1	30.2
	9	22.1–23.1	21.6–21.1	< 0.1	30.8–32.3
	10	24.2–25.0	19.8–19.3	< 0.1	34.7–36.1
Pyroxene	1	8.8–10.3	18.6–17.5	0.11–0.43	17.1–20.4
	2	9.3	18.2	0.19	18.2
	3	9.7	17.7	0.32	19.3
	4	9.7	18.0	0.22	19.0
	5	10.1	18.0	0.27	19.6
	6	10.2–11.4	17.7–16.5	0.34–0.71	20.1–23.1
	7	10.4	17.7	0.36	20.4
	8	10.5–10.6	17.8–17.5	0.30	20.4–20.9
	9	10.6	17.4	0.30	21.0
	10	11.0	17.2	0.52	21.8

TABLE 3—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
	11	11.2	17.0	0.43	22.3
	12	11.3	16.7	0.47	22.8
	13	11.3	17.0	0.41	22.4
	14	11.6	16.9	0.55	23.0
	15	12.0	15.8	0.70	24.9
Chondrule 3					
Olivine	1	7.5	29.8	< 0.1	9.9
	2	8.5	29.5	< 0.1	11.1
	3	8.7	29.0	< 0.1	11.6
	4	8.7	29.0	< 0.1	11.6
	5	9.2–9.5	29.5–28.8	< 0.1	12.0–12.6
	6	9.4	28.4	< 0.1	12.6
	7	9.4	28.6	< 0.1	12.5
	8	9.7	28.5	< 0.1	12.9
	9	9.8–11.3	28.4–27.2	< 0.1	13.0–15.3
	10	10.1	28.5	< 0.1	13.4
	11	10.2	28.3	< 0.1	13.6
	12	10.3	28.3	< 0.1	13.7
	13	10.5	28.1	< 0.1	14.0
	14	10.7	27.2	< 0.1	14.6
	15	11.2	27.9	< 0.1	14.9
	16	11.4–11.7	27.7–27.2	< 0.1	15.2–15.8
	17	19.3–21.5	22.9–21.1	< 0.1	26.8–30.7
Pyroxene	1	6.4	19.5	0.10	12.5
	2	6.4	20.0	0.19	12.2
	3	6.6	19.7	0.10	12.7
	4	6.6	19.8	0.11	12.7
	5	6.8	19.5	0.11	13.2
	6	6.8	19.6	0.11	13.1
	7	7.3	19.3	0.13	14.1
	8	8.5	18.4	0.40	16.7
Chondrule 4					
Olivine	1	9.7	28.3	< 0.1	13.0
	2	11.5	27.5	< 0.1	15.4
	3	11.9	27.3	< 0.1	16.0
	4	11.9	27.2	< 0.1	16.0
	5	12.2	27.3	< 0.1	16.3
	6	12.7–15.3	26.8–25.4	< 0.1	17.1–20.8
	7	12.9–14.6	27.1–26.3	< 0.1	17.2–19.5
	8	12.9–18.8	26.8–23.9	< 0.1	17.3–25.5
	9	14.2–18.2	26.6–24.0	< 0.1	18.9–24.8
	10	14.6	26.7	< 0.1	19.2
	11	15.0	25.6	< 0.1	20.3
	12	16.1–18.6	25.2–23.6	< 0.1	21.8–25.5
	13	16.6–18.0	24.7–23.9	< 0.1	22.6–24.7
	14	16.7–17.0	24.9–24.7	< 0.1	22.6–23.1
	15	17.1	24.6	< 0.1	23.2
	16	19.9–21.2	23.2–19.5	< 0.1	27.2–32.1
	17	20.3	22.1	< 0.1	28.6
Pyroxene	—	—	—	—	—
Chondrule 5					
Olivine	1	2.7	32.0	< 0.1	3.5
	2	3.1–5.3	31.8–31.1	< 0.1	4.1–6.9

TABLE 3—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
	3	3.3–11.0	32.0–28.0	< 0.1	4.3–14.6
	4	3.3–12.2	32.3–27.7	< 0.1	4.3–16.1
	5	4.0–4.2	31.1–31.0	< 0.1	5.3–5.6
	6	5.2	29.0	< 0.1	7.2
	7	5.8–11.5	30.2–26.2	< 0.1	7.7–16.0
	8	7.9–11.3	28.7–27.6	< 0.1	10.7–15.1
Pyroxene	1	0.5	23.1	0.27	0.9
	2	0.8	22.6	0.51	1.5
	3	0.8	23.0	0.36	1.5
	4	0.9	23.2	0.19	1.7
	5	1.3	22 5	0.20	2.5
	6	1.3	22.5	0.31	2.5
	7	1.3	22.7	0.28	2.4
	8	1.3	23.4	0.18	2.4
	9	1.8	22.6	0.22	3.3
	10	2.5	22.6	0.14	4.6
	11	2.7	21.8	0.24	5.1
Chondrule 6					
Olivine	1	13.6	26.2	< 0.1	18.4
	2	13.9	26.3	< 0.1	18.7
	3	14.0	26.2	< 0.1	18.9
	4	16.0	24.6	0.12	22.1
	5	16.3	24.9	< 0.1	22.2
	6	17.3	23.9	< 0.1	24.0
	7	17.7	23.9	< 0.1	24.4
Pyroxene	1	6.0	20.4	0.24	11.4
	2	6.2–9.6	20.0–17.6	0.23–0.87	11.9–19.2
	3	6.5	19.8	0.25	12.5
	4	6.6–8.6	19.6–17.9	0.40–0.95	12.8–17.3
	5	6.7	19.8	0.24	12.8
	6	6.8	19.8	0.17	13.0
	7	6.8	19.8	0.35	13.0
	8	7.3	19.6	0.23	14.0
	9	7.5	19.3	0.26	14.5
	10	7.6	19.4	0.33	14.6
	11	8.1	19.1	0.31	15.6
	12	8.5	18.4	0.47	16.7
	13	8.5	18.7	0.37	16.5
Chondrule 7					
Olivine	—	—	—	—	—
Pyroxene (average)	1–10	8.1	19.3	0.51	15.4
Chondrule 8					
Olivine	1	13.0	25.7	0.13	18.1
Pyroxene	1	5.3	19.7	0.17	10.5
	2	5.4	19.9	0.37	10.6
	3	5.4	20.4	0.19	10.3
	4	5.7	20.4	0.14	10.9
	5	5.8	19.7	0.24	11.4
	6	5.9	20.2	0.17	11.3
	7	5.9	20.3	0.18	11.2
	8	6.3	19.7	0.32	12.2
	9	6.4	18.8	0.76	12.9

TABLE 3—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
	10	6.5	19.7	0.41	12.6
	11	6.5–7.1	18.9–19.8	0.84–2.1	13.0–13.5
	12	6.9	18.4	1.1	14.0
Chondrule 9					
Olivine	1	7.9	29.3	< 0.1	10.4
	2	8.6–13.4	28.9–26.4	< 0.1	11.5–18.1
	3	8.8	28.9	< 0.1	11.7
	4	9.3	29.0	< 0.1	12.3
	5	9.8	28.5	< 0.1	13.0
	6	10.2	28.0	< 0.1	13.6
	7	11.7–12.7	27.1–26.4	< 0.1	15.8–17.3
	8	13.0	26.6	< 0.1	17.5
Pyroxene	1	8.6–10.0	18.1–17.0	0.40–0.64	17.1–20.4
	2	8.7	18.2	0.40	17.2
	3	9.0	17.9	0.50	18.0
Chondrule 10					
Olivine	1	12.0	27.5	< 0.1	16.0
	2	12.4–15.0	27.4–26.0	< 0.1	16.5–20.1
	3	13.7	26.6	< 0.1	18.3
	4	16.2	24.7	< 0.1	22.2
	5	16.2	25.2	< 0.1	21.9
	6	16.5	25.0	< 0.1	22.3
	7	16.6–17.4	24.7–24.0	< 0.1	22.6–24.0
	8	18.3	23.7	< 0.1	25.2
	9	18.9	23.2	< 0.1	26.2
	10	21.3	21.9	< 0.1	29.8
Pyroxene	1	6.6	19.7	0.20	12.7

TABLE 4

COMPOSITION OF COEXISTING OLIVINES AND PYROXENES IN SEPARATED INDIVIDUAL CHONDRULES (FRACTION 2, DIAMETER OF THE CHONDRULES, 1.0 TO 1.4 MM.)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
Chondrule 1					
Olivine	1	12.4	27.2	< 0.1	16.6
	2	12.9	26.9	< 0.1	17.3
	3	13.3	26.7	< 0.1	17.8
	4	13.7	26.4	< 0.1	18.4
	5	13.8	26.2	< 0.1	18.7
	6	14.5–14.8	26.2–26.1	< 0.1	19.4–19.8
	7	14.5–16.6	25.8–22.8	< 0.1	19.7–24.1
	8	17.7	23.5	< 0.1	24.7

TABLE 4—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
Pyroxene	—	—	—	—	—
Chondrule 2					
Olivine	1	4.8	31.3	< 0.1	6.3
	2	5.2	30.7	< 0.1	6.9
	3	5.6	30.5	< 0.1	7.4
	4	5.8	30.9	< 0.1	7.6
	5	7.3	29.8	< 0.1	9.6
	6	7.3	30.0	< 0.1	9.6
Pyroxene	1	4.4	21.0	0.12	8.4
	2	4.5	20.6	0.23	8.7
	3	4.5	20.9	0.16	8.6
	4	4.6	20.8	0.16	8.8
	5	4.7	20.9	0.31	8.9
	6	4.8	20.8	0.16	9.1
Chondrule 3					
Olivine	—	—	—	—	—
Pyroxene	1 to 5	11.2	14.4	1.1	25.3
	6 to 8	11.8	14.7	1.0	25.9
Chondrule 4					
Olivine	1	11.5–13.4	28.0–26.9	< 0.1	15.2–17.8
	2	13.2	26.7	< 0.1	17.7
	3	13.7–14.3	27.0–26.4	< 0.1	18.1–19.1
	4	14.4–15.1	26.0–25.7	< 0.1	19.4–20.4
	5	14.6–14.9	26.0–25.8	< 0.1	19.6–20.1
	6	14.7	26.4	< 0.1	19.5
	7	15.6	25.4	< 0.1	21.1
	8	17.9–18.5	24.1–23.9	< 0.1	24.4–25.2
	9	18.9	22.8	< 0.1	26.5
	10	19.6	23.1	< 0.1	27.0
Pyroxene	—	—	—	—	—
Chondrule 5					
Olivine	—	—	—	—	—
Pyroxene	1	3.1	21.2	0.26	6.0
	2	3.1	21.8	0.11	5.8
	3	3.3	21.6	0.19	6.2
	4	3.6	21.6	0.16	6.8
	5	3.6	21.8	0.19	6.7
	6	3.7	21.4	0.17	7.0
	7	3.8	21.1	0.35	7.3
	8	3.8	21.7	0.12	7.1
	9	4.0	21.0	0.16	7.7
	10	4.0	21.3	0.16	7.6

TABLE 4—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
Chondrule 6					
Olivine	1	12.6	26.9	0.1	16.9
	2	14.1	26.0	0.1	19.1
	3	15.0	25.5	0.1	20.4
	4	15.1	25.4	0.1	20.6
	5	15.1	25.4	0.1	20.6
	6	15.2	25.0	0.1	20.9
	7	15.2	25.2	0.1	20.8
	8	15.2	25.5	0.1	20.6
	9	15.2	25.5	0.1	20.6
	10	15.4	25.3	0.1	20.9
Pyroxene	—	—	—	—	—
Chondrule 7					
Olivine	—	—	—	—	—
Pyroxene	1	4.2	21.3	0.10	7.9
	2	4.5	21.2	0.16	8.5
	3	4.7	21.0	0.23	8.9
	4	4.8	20.8	0.16	9.1
	5	5.1	20.5	0.42	9.8
	6	5.4	20.2	0.27	10.4
	7	5.4	20.6	0.24	10.2
	8	5.7	20.1	0.35	11.0
	9	5.7	20.4	0.27	10.9
	10	5.8	20.0	0.24	11.2
	11	6.1	18.9	1.1	12.3
	12	6.4	19.6	0.43	12.4
Chondrule 8					
Olivine	1	13.2	26.6	< 0.1	17.8
Pyroxene	1	8.1	18.6	0.30	15.9
	2	8.4	18.8	0.25	16.3
	3	8.5	18.9	0.32	16.4
	4	8.6	19.6	0.35	16.0
	5	8.8	18.4	0.37	17.2
	6	9.2	17.6	0.57	18.5
	7	9.2	18.5	0.19	17.8
	8	9.4	18.0	0.20	18.5
	9	9.5	18.5	0.31	18.3
Chondrule 9					
Olivine	1	2.8	31.5	< 0.1	3.7
	2	3.0	31.8	< 0.1	3.9
	3	3.2	31.8	< 0.1	4.2
	4	3.8	31.2	< 0.1	5.0
Pyroxene	1	0.9	22.6	0.37	1.7

TABLE 4—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
	2	0.9	23.1	0.21	1.7
	3	1.0	22.9	0.30	1.9
	4	1.0	23.4	0.13	1.8
	5	1.0	23.5	0.14	1.8
	6	1.1	22.7	0.35	2.1
	7	1.1	23.0	0.15	2.0
	8	1.1	23.1	0.26	2.0
	9	1.1	23.3	0.21	2.0
	10	1.4	22.7	0.15	2.6
Chondrule 10					
Olivine	1–13	18.9–19.5	23.4–23.3	< 0.1	26.0–26.7
Pyroxene	—	—	—	—	—
Chondrule 11					
Olivine	1	6.1	30.1	< 0.1	8.1
	2	6.5	30.1	< 0.1	8.6
	3	6.8	30.0	< 0.1	9.0
	4	7.0	29.9	< 0.1	9.2
	5	7.1	29.7	< 0.1	9.4
	6	7.9	29.6	< 0.1	10.4
	7	7.9	29.8	< 0.1	10.4
	8	8.0–9.2	29.4–29.0	< 0.1	10.6–12.1
	9	8.2	29.4	< 0.1	10.8
	10	10.0	28.0	< 0.1	13.5
Pyroxene	1–2	7.3	18.8	1.5	14.5
Chondrule 12					
Olivine	—	—	—	—	—
Pyroxene	1–7	6.2	19.5	1.0	12.2

TABLE 5

COMPOSITION OF COEXISTING OLIVINES AND PYROXENES IN SEPARATED INDIVIDUAL CHONDRULES (FRACTION 3, DIAMETER OF THE CHONDRULES, 0.4 TO 0.6 MM.)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
Chondrule 1					
Olivine	1	0.1	33.5	0.35	0.1
	2	0.1	33.5	0.36	0.1
	3	0.4	33.5	0.16	0.5
	4	0.8	32.3	0.17	1.1
	5	1.2–2.1	31.8–31.5	0.17	1.6–2.8

TABLE 5—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
Pyroxene	—	—	—	—	—
Chondrule 2					
Olivine	1	10.2–11.6	28.6–27.8	< 0.1	13.4–15.4
	2	10.4	28.0	< 0.1	13.9
	3	10.5–12.3	28.2–26.9	< 0.1	14.0–16.6
	4	13.1	26.5	< 0.1	17.7
	5	14.2	26.0	< 0.1	19.2
	6	16.1–16.6	24.6–24.3	< 0.1	22.2–22.9
Pyroxene	1	9.6	16.9	1.6	19.8
Chondrule 3					
Olivine	—	—	—	—	—
Pyroxene	1	2.3	22.0	0.18	4.4
	2	2.7	21.9	0.48	5.1
	3	3.1	22.1	0.17	5.8
	4	4.4	20.5	0.50	8.5
Chondrule 4					
Olivine	—	—	—	—	—
Pyroxene	1–2	0.6	19.2	1.2	1.3
Chondrule 5					
Olivine	1	0.1	33.0	0.33	0.1
	2	0.1	33.2	0.17	0.1
	3	0.1	33.4	0.30	0.1
	4	0.2	33.0	0.27	0.3
Pyroxene	—	—	—	—	—
Chondrule 6					
Olivine	1	4.3	31.3	< 0.1	5.6
	2	4.5	30.9	< 0.1	6.0
	3	4.9	31.0	< 0.1	6.4
	4	5.5	30.8	0.15	7.2
	5	5.9	30.3	< 0.1	7.8
	6	6.6	30.1	< 0.1	8.7
Pyroxene	1	2.8	22.1	0.32	5.2
Chondrule 7					
Olivine	—	—	—	—	—
Pyroxene	1	4.1	21.3	< 0.1	7.7
	2	4.1	21.3	< 0.1	7.7
	3	4.1–5.3	21.3–20.0	0.19	7.7–10.3
	4	4.4	21.0	0.12	8.4
Chondrule 8					
Olivine	1	4.5–5.5	31.1–29.9	< 0.1	5.9–7.4
Pyroxene	1	3.5	21.6	0.12	6.6
	2	3.6	21.7	0.11	6.7
	3	3.8–4.4	21.2–20.6	0.20–0.46	7.2–8.5

TABLE 5—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
	4	4.6	21.2	0.19	8.6
Chondrule 9					
Olivine	1	15.5	25.3	< 0.1	21.1
Pyroxene	1	6.7	19.6	0.31	13.0
	2	6.8	20.0	0.15	12.9
	3	6.9	19.9	0.26	13.1
	4	7.0	19.6	0.30	13.5
	5	7.0	19.9	0.24	13.3
Chondrule 10					
Olivine	1	7.9	29.4	< 0.1	10.5
	2	7.9	29.4	< 0.1	10.5
	3	8.1	29.4	< 0.1	10.7
	4	8.6	29.2	< 0.1	11.4
	5	9.0	29.0	< 0.1	11.9
Pyroxene	—	—	—	—	—
Chondrule 11					
Olivine	1	2.5–2.8	32.2–31.8	< 0.1	3.3–3.7
	2	3.4	31.8	< 0.1	4.5
Pyroxene	1	1.0	23.0	0.10	1.9
	2	1.1	23.1	0.10	2.0
	3	1.3	23.0	0.25	2.4
	4	1.5	22.7	0.21	2.8
	5	1.8	23.0	0.13	3.3
Chondrule 12					
Olivine	1	5.0	31.0	< 0.1	6.6
Pyroxene	1	1.0	23.4	0.15	1.8
	2	1.1	23.2	0.11	2.0
	3	1.1	23.4	0.10	2.0
	4	1.2	22.9	0.18	2.2
	5	1.2	23.0	0.27	2.2
	6	1.2	23.0	0.18	2.2
	7	1.3	22.9	0.13	2.4
Chondrule 13					
Olivine	1	5.7	30.8	< 0.1	7.5
Pyroxene	1	2.6	22.1	0.16	4.9
	2	2.8	21.7	0.42	5.3
	3	2.8	21.9	0.24	5.3
	4	2.9	22.1	0.11	5.4
	5	3.3	21.9	0.23	6.2
Chondrule 14					
Olivine	1	6.1	30.1	< 0.1	8.1
Pyroxene	1	1.7	22.4	0.20	3.2
	2	1.8	22.4	0.18	3.4

TABLE 5—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
	3	2.3–3.0	22.4–21.6	0.14–0.24	4.3–5.7
	4	2.4	21.8	0.19	4.6
	5	2.6	21.9	0.29	4.9
	6	3.2	21.3	0.28	6.1

TABLE 6

COMPOSITION OF COEXISTING OLIVINES AND PYROXENES IN SEPARATED INDIVIDUAL CHONDRULES (FRACTION 4, DIAMETER OF THE CHONDRULES, 0.3 TO 0.4 MM.)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
Chondrule 1					
Olivine	1	5.0	30.6	< 0.1	6.6
	2	5.9	30.8	< 0.1	7.7
	3	6.7	30.1	< 0.1	8.8
Pyroxene	—	—	—	—	—
Chondrule 2					
Olivine	—	—	—	—	—
Pyroxene	1–4	0.6	20.9	2.1	1.2
Chondrule 3					
Olivine	1	2.5	31.6	< 0.1	3.3
Pyroxene	1	0.8	22.9	0.14	1.5
	2	0.8	22.9	0.15	1.5
	3	0.9	22.8	0.27	1.7
	4	0.9	22.8	0.19	1.7
	5	0.9	23.0	0.10	1.7
	6	1.1	22.8	0.11	2.1
Chondrule 4					
Olivine	1	3.5	31.5	< 0.1	4.6
	2	3.8	31.3	< 0.1	5.0
Pyroxene	1	1.0	22.4	0.30	1.9
	2	1.5	22.0	0.25	2.9
	3	1.8	22.1	0.41	3.4
	4	1.8	22.2	0.27	3.4
	5	2.2	22.5	0.14	4.1
Chondrule 5					
Olivine	1	1.3–1.8	31.6–31.2	< 0.1	1.8–2.4
	2	1.7	31.8	< 0.1	2.3
	3	2.2–4.1	31.0–29.8	< 0.1	3.0–5.7

TABLE 6—(*Continued*)

	Grain Number	Weight Per Cent Fe	Mg	Ca	Mol Per Cent Fe/Fe+Mg
	4	8.3	28.6	< 0.1	11.2
Pyroxene	—	—	—	—	—
Chondrule 6					
Olivine	1	1.8	31.9	< 0.1	2.4
	2	1.9	31.8	< 0.1	2.5
	3	2.8–3.5	31.1–30.7	< 0.1	3.8–4.7
Pyroxene	—	—	—	—	—
Chondrule 7					
Olivine	1	5.4	30.4	< 0.1	7.2
	2	5.9	29.5	< 0.1	8.0
Pyroxene	1	2.9	21.2	0.6	5.6
	2	2.9	21.2	0.5	5.6
	3	3.1	20.6	1.0	6.1
Chondrule 8					
Olivine	—	—	—	—	—
Pyroxene	1	0.5	23.2	0.45	1.0
	2	0.7	23.1	0.49	1.3
Chondrule 9					
Olivine	1	15.6	24.7	< 0.1	21.6
	2	21.6	20.4	< 0.1	31.6
	3	22.7	20.6	< 0.1	32.4
Pyroxene	1	5.0	20.6	0.20	9.6
	2	5.7–6.4	20.6–19.7	0.21	10.8–12.4
Chondrule 10					
Olivine	1	6.7–8.9	30.1–28.8	< 0.1	8.8–11.9
	2	22.3	20.6	< 0.1	32.0
Pyroxene	1	4.9	20.3	0.38	9.5

DISCUSSION

From its chemical composition Chainpur would be classified as an olivine-hypersthene chondrite, as originally defined by Prior (1920). However, in the variability of its olivine composition and the presence of clinopyroxene instead of orthopyroxene it resembles the olivine-pigeonite chondrites, and was so classified by Mason (1962, p. 93) on the basis of a preliminary examination. It also resembles some of the olivine-pigeonite chondrites in the probable presence of organic matter in the groundmass. It differs from them, however, in its low total-iron content (20%); the olivine-pigeonite chondrites have a total iron content similar to that of the high-iron group of Urey and Craig, with an average content of

around 26 per cent. In brief, Chainpur is an olivine-hypersthene chondrite in chemical composition and an olivine-pigeonite chondrite in mineralogy (and structure).

The remarkable feature of Chainpur that distinguishes it from most other chondrites is the variability in olivine and pyroxene composition from chondrule to chondrule, and even within individual grains inside a single chondrule. Normally in a chondrite the olivine and pyroxene are remarkably uniform in composition throughout, as is shown by the sharp reflections in X-ray diffraction patterns, and has been clearly demonstrated in the Pantar chondrite by microprobe analyses of the individual grains (Fredriksson and Keil, 1963). The explanation of this peculiar feature of the Chainpur meteorite is clearly highly significant in terms of its origin and history. The problem is essentially one of the non-equilibrium state of the individual grains within a single chondrule. However the chondrules formed, they either crystallized rapidly or at a temperature too low for diffusion to be effective in eliminating composition gradients.

At this point it is desirable to recapitulate briefly current theories of the origin of chondrules. These may be considered in two groups, as follows:

1. Chondrules originated as molten droplets—the classical and widely accepted theory. Ringwood (1961) believed that crystallization temperatures were depressed below 1000° C. by the presence of volatiles (H_2O and CO_2) under high pressure. Wood (1962) suggested that chondrules condensed as liquid droplets from cooling solar gases during the formation of the sun.

2. Chondrules originated by the recrystallization of solid matter at temperatures below the melting point. Levin and Slonimsky (1958) favored an origin by direct condensation from a cool dust cloud in which the particles were essentially in the colloidal state; they considered the original chondrules to have been amorphous, and to have been crystallized by later heating processes. Mason (1960) suggested that chondrules have been formed by the thermal metamorphism of hydrated magnesium-iron silicates such as make up the bulk of the Type I and Type II carbonaceous chondrites.

The microprobe analysis data on the chondrules can be interpreted as favoring their origin by crystallization from a melt under somewhat different conditions from those of most chondrites. The constancy of composition of olivine and pyroxene in a normal chondrite (as, for example, Pantar) can be the result of extremely rapid cooling (i.e., a frozen equilibrium). In Chainpur, however, the cooling, while rapid, was somewhat slower than in the normal chondrites. The chondrules of

TABLE 7

COMPILATION OF THE MAXIMA AND MINIMA VALUES FOR FE, MG, AND FE /FE+MG IN OLIVINE AND PYROXENE IN INDIVIDUAL CHONDRULES

			Olivine				Pyroxene			
	No. in Fig. 3	Nos. of Individual Grains Analyzed	Weight of Fe	Per Cent of Mg	Mol Per Cent Fe /Fe+Mg	Nos. of Individual Grains Analyzed	Weight of Fe	Per Cent of Mg	Mol Per Cent Fe /Fe+Mg
Fraction 1									
Chondrule 1	—	—	—	—	—	20	7.5–10.4	19.0–17.1	14.9–20.9
2	7	10	14.1–25.0	26.6–19.3	18.8–36.1	15	8.8–12.0	18.6–15.8	17.1–24.9
3	2	17	7.5–21.5	29.8–21.1	9.9–30.7	8	6.4– 8.5	20.0–18.4	12.2–16.7
4	—	17	9.7–21.2	28.3–19.5	13.0–32.1	—	—	—	—
5	1	8	2.7–12.2	32.3–26.2	3.5–16.1	11	0.5– 2.7	23.4–21.8	0.9– 5.1
6	6	7	13.6–17.7	26.3–23.9	18.4–24.4	13	6.0– 9.6	20.4–17.6	11.4–19.2
7	—	—	—	—	—	10	8.1	19.3	15.4
8	5	1	13.0	25.7	18.1	12	5.3– 7.1	20.4–18.4	10.3–14.0
9	3	8	7.9–13.4	29.3–26.4	10.4–18.1	3	8.6–10.0	18.2–17.0	17.1–20.4
10	4	10	12.0–21.3	27.5–21.9	16.0–29.8	1	6.6	19.7	12.7
Fraction 2									
Chondrule 1	—	8	12.4–17.7	27.2–22.8	16.6–24.7	—	—	—	—
2	2	6	4.8– 7.3	31.3–29.8	6.3– 9.6	6	4.4– 4.8	21.0–20.6	8.4– 9.1
3	—	—	—	—	—	8	11.2–11.8	14.4–14.7	25.3–25.9
4	—	10	11.5–19.6	28.0–22.8	15.2–27.0	—	—	—	—

TABLE 7—(*Continued*)

				Olivine				Pyroxene		
	No. in Fig. 3	Nos. of Individual Grains Analyzed	Weight of Fe	Per Cent of Mg	Mol Per Cent Fe/Fe+Mg	Nos. of Individual Grains Analyzed	Weight of Fe	Per Cent of Mg	Mol Per Cent Fe/Fe+Mg
5	—	—	—	—	—	10	3.1– 4.0	21.8–21.0	5.8– 7.7
6	—	10	12.6–15.4	26.9–25.0	16.9–20.9	—	—	—	—
7	—	—	—	—	—	12	4.2– 6.4	21.3–18.9	7.9–12.4
8	4	1	13.2	26.6	17.8	9	8.1– 9.5	19.6–17.6	15.9–18.5
9	1	4	2.8– 3.8	31.8–31.2	3.7– 5.0	10	0.9– 1.4	23.5–22.6	1.7– 2.6
10	—	13	18.9–19.5	23.4–23.3	26.0–26.7	—	—	—	—
11	3	10	6.1–10.0	30.1–28.0	8.1–13.5	2	7.3	18.8	14.5
12	—	—	—	—	—	7	6.2	19.5	12.2
Fraction 3									
Chondrule 1	—	5	0.1– 2.1	33.5–31.5	0.1– 2.8	—	—	—	—
2	7	6	10.2–16.6	28.6–24.3	13.4–22.9	1	9.6	16.9	19.8
3	—	—	—	—	—	4	2.3– 4.4	22.1–20.5	4.4– 8.5
4	—	—	—	—	—	2	0.6	19.2	1.3
5	—	4	0.1– 0.2	33.4–33.0	0.1– 0.3	—	—	—	—
6	2	6	4.3– 6.6	31.3–30.1	5.6– 8.7	1	2.8	22.1	5.2
7	—	—	—	—	—	4	4.1– 5.3	21.3–20.0	7.7–10.3
8	3	1	4.5– 5.5	31.1–29.9	5.9– 7.4	4	3.5– 4.6	21.7–20.6	6.6– 8.6
9	8	1	15.5	25.3	21.1	5	6.7– 7.0	20.0–19.6	13.0–13.5

TABLE 7—(*Continued*)

			Olivine			Pyroxene			
	No. in Fig. 3	Nos. of Individual Grains Analyzed	Weight of Fe	Per Cent of Mg	Mol Per Cent Fe/Fe+Mg	Nos. of Individual Grains Analyzed	Weight of Fe	Per Cent of Mg	Mol Per Cent Fe/Fe+Mg
10	—	5	7.9– 9.0	29.4–29.0	10.5–11.9	—	—	—	—
11	1	2	2.5– 3.4	32.2–31.8	3.3– 4.5	5	1.0– 1.8	23.1–22.7	1.9– 3.3
12	4	1	5.0	31.0	6.6	7	1.0– 1.3	23.4–22.9	1.8– 2.4
13	5	1	5.7	30.8	7.5	5	2.6– 3.3	22.1–21.7	4.9– 6.2
14	6	1	6.1	30.1	8.1	6	1.7– 3.2	22.4–21.3	3.2– 6.1
Fraction 4									
Chondrule 1	—	3	5.0– 6.7	30.8–30.1	6.6– 8.8	—	—	—	—
2	—	—	—	—	—	4	0.6	20.9	1.2
3	1	1	2.5	31.6	3.3	6	0.8– 1.1	23.0–22.8	1.5– 2.1
4	2	2	3.5– 3.8	31.5–31.3	4.6– 5.0	5	1.0– 2.2	22.5–22.0	1.9– 4.1
5	—	4	1.3– 8.3	31.8–28.6	1.8–11.2	—	—	—	—
6	—	3	1.8– 3.5	31.9–30.7	2.4– 4.7	—	—	—	—
7	3	2	5.4– 5.9	30.4–29.5	7.2– 8.0	3	2.9– 3.1	21.2–20.6	5.6– 6.1
8	—	—	—	—	—	2	0.5– 0.7	23.2–23.1	1.0– 1.3
9	5	3	15.6–22.7	24.7–20.4	21.6–32.4	2	5.0– 6.4	20.6–19.7	9.6–12.4
10	4	2	6.7–22.3	30.1–20.6	8.8–32.0	1	4.9	20.3	9.5

Chainpur do not represent a frozen equilibrium, but, since the cooling was slower, produced a zonar structure in the olivine and pyroxene. Possibly normal chondrites cooled in a period of seconds, whereas Chainpur took perhaps minutes or hours. Such a process has been discussed in more detail by Fredriksson (1963).

The properties of the chondrules in Chainpur can also be interpreted in terms of their origin by a thermal metamorphism of hydrated magnesium-iron silicate. Under conditions of thermodynamic equilibrium, the formation of olivine can be predicted to take place at temperatures of 200° C. and higher (Bennington, 1956). At the lowest temperatures of olivine formation the initial phase will be essentially pure Mg_2SiO_4, and, as the temperature increases, an increasing degree of substitution of Fe for Mg can be expected, hence the increase in the Fe/Mg ratio from the center to the periphery of the individual olivine crystals (fig. 2). In most chondrites the maximum temperature and the duration of this thermal metamorphism were sufficient to produce minerals of essentially homogeneous composition. In Chainpur the thermal metamorphism was presumably interrupted before the process could go to completion.

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